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RESULTS OF THE EXPERIMENTS ON THE DETECTION OF LUNAR IONOSPHERE CONDUCTED ON THE FIRST ARTIFICIAL SATELLITE OF THE MOON

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SUMMARY

The experiments for the detection of lunar ionosphere, carried out on LUNA-10, were based upon the use of two traps for the respective registrations of low-energy positive ions and electrons. The results of observation of zones of increased concentration are discussed. The final results arrived at probably still are considerably overrated ($n_i \leqslant 100$ cm^{-3} and $n_e \leqslant 300$ cm^{-3}), which is due to side effects to be discussed in subsequent papers.

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Among other devices, two charged particle traps were installed on AMS "LUNA-10", which were designed for the registration of positive ions and electrons of low energies [1]. Preliminary data obtained with the aid of these traps are presented in the current communication.

Two hypotheses on the existence near the Moon of a region with high concentration of charged particles by comparison with interplanetary space, i. e. of lunar ionosphere, was based upon the fact that the gravitational field of the Moon is sufficient to retain the atoms of heavy gases (for example, argon), of which the source may be in the solar plasma fluxes as well as in radioactive decay of potassium. Besides, hydrogen atoms, vaporizing from the surface of the Moon (neutralized solar wind protons) may also create a certain concentration of low-energy protons near the Moon as a consequence of charge-exchange with the positive ions of the solar wind.

Calculations of [2 –4] for various model ionospheres lead to charged particle concentration within the limits $5 \cdot 10^1 - 10^3$ cm^{-3} . Experimental estimates

(*) REZUL'TATY EKSPERIMENTOV PO OBNARUZHENIYU LUNNOY IONOSFERY PROVEDENNYKH NA PERVOM ISKUSSTVENNOM SPUTNIKE LUNY of the upper limit of electron concentration n_e in the near-lunar space were obtained by observation of radiowave refraction during eclipse by the Moon of a series of radiosources. Thus, the estimate $n_e \sim 10^3 - 10^4$ cm^{-3} as a function of the height $\underline{h}$ of uniform atmosphere from 80 to 5000 km was obtained in 1956 from Crab Nebula eclipse observation [5]. By observing the eclipse of radiosource 3C 273 in 1963, the upper limit of n_e near the Moon was lowered to $100 - 200$ cm^{-3} (in the assumption that $h \sim 80$ km) [6, 7].

Besides the smallness of the quantity determined, the difficulties of a direct measurementsof charged particle concentration in the ionosphere of the Moon are aggravated by the uncertainty of information relative to satellite's electric potential. In connection with this, two traps were applied aboard LUNA-10: one designed to measure the concentration of thermal positive ions, whose registration is possible provided the satellite's potential $\phi_{sat} \lesssim 0$, the other destined to the measurement of the concentration of thermal electrons when $\phi_{sat} \gtrsim 0$. The circuits of the traps and the values of voltages in electrodes relative to satellite frame are schematized in Fig.1. The ion trap (a) is a modulation trap; it consists of two identical traps with interconnected collectors, close by their construction to the trap described in [8]. Such a construction allowed us to significantly expand the angular characteristic of the trap. An alternate voltage of rectangular shape from -3 to $+7$ v was fed to the modulation grid. The variable component of collector current was registered by a resonance amplifier, tuned to the modulation frequency.

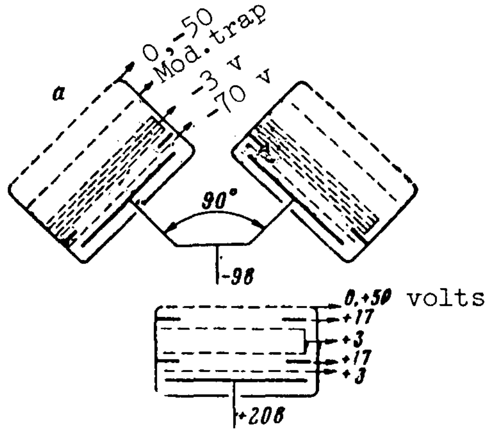

Fig.1

Compared to the three-electrode traps with constant potential in electrodes, installed on other Soviet spacecrafts [8, 9], some changes were introduced in the construction of the present trap so as to decrease the outer grid's photocurrent and reduce the details of its fastening. The potentials of outer grids of the traps were changed once every two minutes in a jump-like fashion and constituted either 0, or 50 v fro the electron trap. At trap's amplifier output the signal was proportional to collector current when the latter is negative, and was absent when the current was positive.

The diposition of traps aboard LUNA-10 and the Moon's projection on the ecliptic plane for the considered moments of time are schematically represented in [1].

If the speed of the spacecraft exceeds the thermal velocity of ions or close to its average, the ion trap current I_p depends essentially on the orientation of the plane trap relative to velocity vector. Measurements of collector currents in each of the traps were conducted once every 2 min for radiocommunication sessions, as satellite's rotation period was ~ 40 sec. It is quite possible that precisely because of that the values of I_p varied rather irregularly. The bulk of readings (of the total number ~ 450) lied within the limits from $3 - 5 \cdot 10^{-12}$a.

Plotted in Fig.2 are the values of I_p measured in interplanetary space (A) and during the Moon's sojourn in the assumed extension of Earth's magnetosphere tail [1] at various altitudes H from the surface of the Moon (b) From the graph constructed by utilizing the values of I_p obtained during various satellite orb bits around the Moon, it may be seen that there is no notable dependence of I_p on H. Comparison of values of I_p during the sojourn of the Moon in the magnetosphere tail and in interplanetary space corroborates the conclusion made in [1] on the difference in the fluxes of charged particles in these regions of space on the Moon's orbit. Thus, in the first case the mean value of I_p is

$$I_p' = (2.3 \pm 0.1) \cdot 10^{-12} a,$$

and in the second case it is

$$I_p'' = (3.1 \pm 0.1) \cdot 10^{-12} a.$$

If we consider that the current of the modulation trap is determined only by thermal ions (see further about another possibility), we may estimate by the measured values of I_p the upper limit of their concentration assuming $\phi_{sat} \lesssim 0$ and that the maximum values of I_p correspond to the coincidence of the normal to collector trap with the direction of velocity vector. The scanning sector of this trap (0.1 at level) constitutes $\sim {}^1/_3$ of the entire space and this is why the latter assumption appears to be quite probable provided a large number of measurements at various portions of the orbit around the Moon is taken into account.

The effective area of the collector trap constitutes 14 cm^2. Taking into account all the above considerations, the maximum values of I_p give an estimate of the upper limit of ion concentration $n_i \sim 100$ cm^{-3}, provided we consider the directed velocity of the satellite ($\sim$1 km/sec) much greater than the thermal velocity of ions, in other words, if we consider the Moon's ionosphere consisting of heavy ions. But if the ionosphere consists of hydrogen ions with temperature $\sim 10^3 - 10^4$°K, this estimate will have to be lowered by 2 to 3 times.

The electron trap current I_e fluctuates in most of the measurement sessions within a broad range, from 10^{-10} to $2.2 \cdot 10^{-9}$ a (see Fig.3). All readings may be subdivided into two sharply differing groups: the "large" currents $(1.8-2.2) \cdot 10^{-9}$a) and the "small"currents $(1-9) \cdot 10^{-10}$a, and the intermediate values are nearly never met with.

The "large" values of I_e are apparently explained by photoelectron flux hitting the trap in the satellite rotation process; these photoelectrons are emitted under the action of solar radiation from the closest portions of spacecraft's surface. Estimate of photocurrent from trap's grids, taking into account laboratory measurements, give $(3-4) \cdot 10^{-10}$ a. The "small" values of I_e are also differing notably when the Moon is located in the Earth's magnetosphere tail (Fig.3b). Thus, the mean value of I_e in the magnetosphere is equal to $(4.8 \pm 0.1) \cdot 10^{-10}$ a, while in interplanetary space I_e does not drop below $4 \cdot 10^{-10}$a amd its mean value is $(7.2 \pm 0.1) \cdot 10^{-10}$ a.

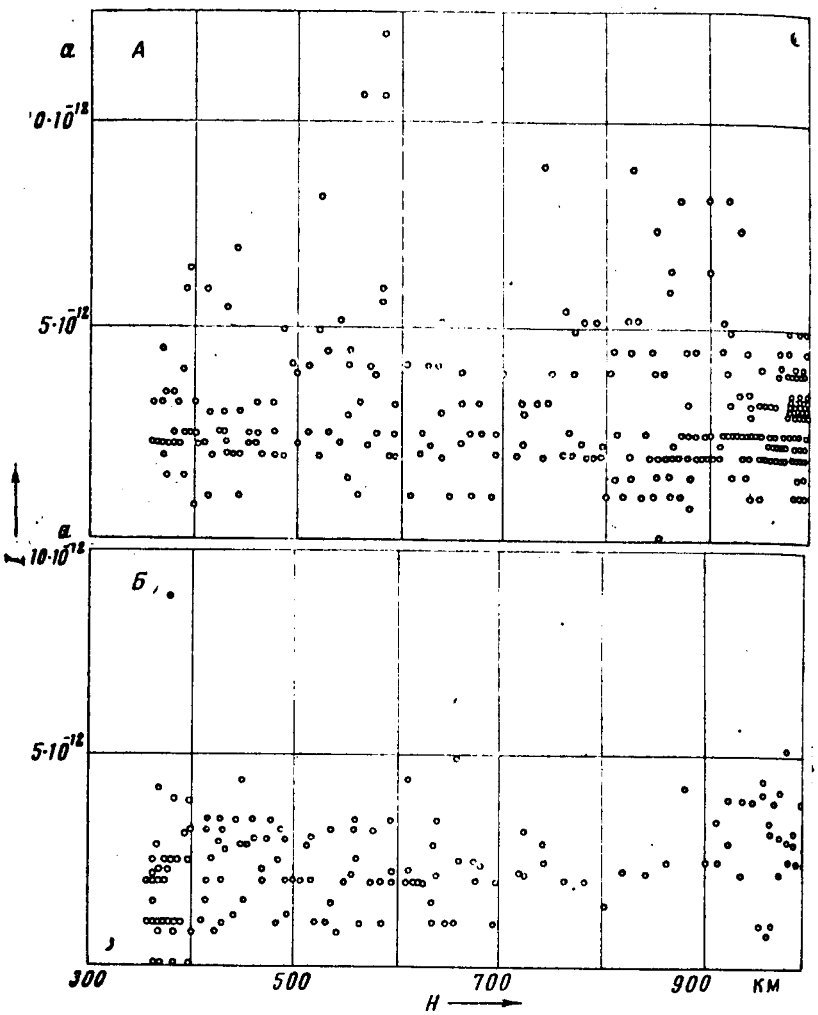

Fig.2

Interpreting the "small" values of currents as if they were induced by isotropic fluxes of electrons, and assuming $\phi_{sat} \geqslant 0$, it is possible to estimate the upper boundary of low-energy electron concentration in the near-lunar space. Taking into account the possible shift of the zero level on account of the trap being hit by fluxes of ions with E > 20 ev, the estimate of concentration of electrons with energy E $\sim$ 1 ev gives $n_e \sim 80$ cm^{-3} for the Moon located in interplanetary space and $n_e \sim 60$ cm^{-3} for the Moon in the Earth's magnetosphere.

It is of interest to estimate the values of n_e by the data obtained during the session of 3 May 1966, when the satellite was in Moon's shadow and the photocurrent must have been absent. In this session the current of the electron trap fell by $\sim 2 \cdot 10^{-11}$ a which, ta ing into account the indicated zero shift, gives $n_e \sim 15-20$ cm^{-3}. It is possible, however, that the current decrease in the electron trap is the consequence of satellite potential shift toward the negative values (because of cessation of photoemission from its surface).

We should point to a series of effects taking place during measurements with the modulation and electron traps, the accounting of which being susceptible to lead to different explanations of the origin of the observed electrons, and, consequently, to a decrease of the indicated estimates of the upper limit of concentration of thermal charged particles in the Moon's ionosphere. Flux modulation of ions with energy $E \gg eU_m$, U_m being the alternate voltage on the modulation grid, may take place to a certain, though small degree, in the modulation trap during an inclined incidence of the beam of charged particles. A rough computation for the trap under consideration shows that the current's variable component is proportional to thousandths of fractions of solar wind's proton flux. Assuming for the estimate the maximum value of solar wind flux, measured by integral traps on LUNA-10 [1], we shall obtainefor the energy of protons $\sim$ 200 ev a value of current's variable component $I \sim 3 \cdot 10^{-12}$ a, which is close to the really observed value of I_p. A series of other facts, such as the absence of noticeable dependence of modulation trap's current on outer grid potnntial and the absence of a notable altitude course of the current, are also evidence in favor of the assumption that the modulation trap's variable current is induced by a flux of ions with ehergy substantially exceeding the thermal energy. It is obvious that the accounting of the factors indicated may only lead to lowering the above estimate of the upper limit of concentration of thermal ions.

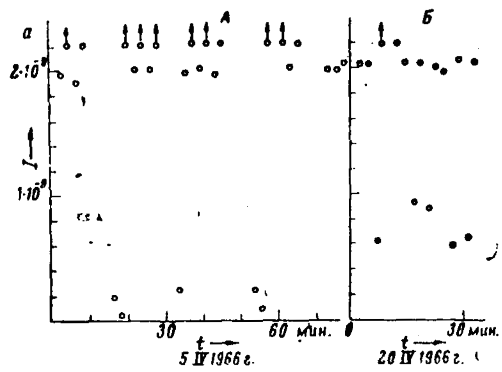

Fig.3

The estimate of the value of n_e by the data of electron trap must be corrected by the value of the possible "interception" of low-energy electrons by other electrodes of the trap. According to data of preliminary laboratory investigations for electrons with energy $E \sim 1$ ev, the above estimates of n_e must apparently be of necessity increased by 3 to 4 times. On the other hand, it is not possible to exclude the possibility that part of the electron trap current is induced by the flux of photoelectrons from the surface of the satellite. Taking this circumstance into account can only lead to a lowering of the obtained estimate of the upper limit of n_e.

It may be assumed that the estimates of the upper limit of concentration of thermal charged particles in the near-lunar space according to data of the ion ($n_i \lesssim 100$ cm^{-3}), as well as of the electron ($n_e \lesssim 300$ cm^{-3}) traps are much rather notably overrated as a consequence of the influence of the indicated side effects, of which a more detailed discussion will be carried out in the future.

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